OREGON DEPARTMENT OF AGRICULTURE

NATIVE PLANT CONSERVATION PROGRAM

Evaluating population viability and the effects of fire on *Kalmiopsis fragrans*

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Introduction

Kalmiopsis fragrans Meinke and Kaye is a rare perennial shrub endemic to a narrow band of rocky habitat in the Umpqua National Forest in Douglas County, Oregon. Populations of *K. fragrans* inhabit openings in forested areas, and forest wildfires have been suggested as a threat to the persistence of this species (Carlson 2005, personal communication). However, prior to the current study, the effects of fire on this species had not been evaluated. Wildfires in 1996 and 2002 burned two of the 15 known sites of this plant, providing an opportunity to quantify the effects of burning on the viability of this unusual species. This multi-year study, begun in 2004, evaluates the effects of fire on growth and reproduction of *K. fragrans*. In addition, this study also and provides information on seed germination and seedling cultivation methodology that is valuable in determining the potential for sexual reproduction and recruitment in this species.

Background

Species description

A recently described member of the heath family (Ericaceae), *Kalmiopsis fragrans* is a perennial, evergreen, low-growing shrub which produces bright pink, relatively large, open campanulate flowers (Meinke and Kaye 2007: Figure 1). Plants of this species exhibit stigma height dimorphism, with distinct short- and long-styled flower morphs present in most populations. Flowers appear in April and May, and large numbers of tiny seeds are typically produced in dry, dehiscent capsules later in the summer (Carlson and Meinke 1998). Although copious seed is

Figure 1. Flowers of *Kalmiopsis fragrans*. Photo by I. Silvernail.

produced, seedlings are rarely observed, and reproduction is assumed to be primarily vegetative, through adventitious root formation on low-lying branches and elongate underground stems (Meinke and Kaye 2007).

Habitat

Kalmiopsis fragrans grows primarily on rocky outcrops, on or adjacent to pillars or boulders within the Umpqua National Forest (Meinke and Kaye 2007). The altered andesite substrate typical of these sites has a poorly developed soil layer, resulting in harsh and inhospitable growing conditions. The associated cool, mesic, mixed conifer forests are dominated by *Pseudotsuga menziesii*, *Abies grandis*, *Tsuga heterophylla*, *Calocedrus decurrens*, *Thuja plicata* and *Pinus lambertiana*. Because only 15 populations of this species have been located since its discovery in the 1970s, *Kalmiopsis fragrans* is listed as a Species of Concern by the U.S. Fish and Wildlife Service (USFWS), and is included on the U.S. Forest Service's (USFS) list of Sensitive Plants (Emerson 2003, ORNHIC 2004). This species is also on the Oregon Natural Heritage Information Center's G1/S1 list (critically imperiled throughout its range/critically imperiled in Oregon; ORNHIC 2004).

Threats

In addition to fire, potential threats to this species include over-collection and disturbance due to timber harvest activities. In the past, plants of *Kalmiopsis fragrans*, and the closely related *K. leachiana*, were commercially collected for the nursery trade, and over-collection may have contributed to the loss of populations of the latter species (Meinke and Kaye 2007). Fortunately, *K. fragrans* is now listed as Sensitive by USFS, and Forest Service policy allows collection of this species for scientific purposes only - commercial collecting is prohibited. Although all populations of *K. fragrans* occur in forested areas, the steep rocky slopes preferred by this species probably preclude any direct impact from timber harvest activities. Recent wildfires in areas where *K. fragrans* grows most likely present the greatest threat to this species; a need for further data quantifying the effect of fire provided the impetus for the current monitoring study.

Seed viability

Seedlings of *K. fragrans* have very rarely been documented in naturally occurring populations (Marquis 1977), and this lack of evidence for recruitment of new plants through sexual reproduction has been cause for concern. No seedlings or juvenile plants were observed at any of the sites visited during our study, although plants appeared to be increasing by layering (rooting of prostrate stems at points of contact with the soil). The lack of observed seedlings of *Kalmiopsis fragrans* may be due to a number of causes. Infrequent and erratic seedling recruitment may be a natural part of the life history strategy of this species, which may rely largely on vegetative layering for population persistence. Alternatively, the production of genetically inviable seed in the small populations in which this plant occurs has been suggested as the cause of the observed lack of seedlings - poor germination rates frequently result from the inbreeding depression common in small populations (Schemske and Lande 1985).

Inviable seeds may also be produced due to maternal resource limitation (Winn 1985). The harsh sites inhabited by *K. fragrans* may routinely provide minimally sufficient moisture or other resources to promote viable seed maturation, and these limitations may be increased due to the microhabitat alterations of a major fire. A final scenario might be that seeds are viable, but conditions in sites currently occupied by adults are not suitable for seed germination, seedling maturation, or juvenile survivorship (Eriksson 2002). Evaluation of seed viability and germinability under controlled conditions provides information valuable in determining the cause of the dearth of seedlings observed in naturally occurring populations of this species.

Seed germination

General recommendations for sowing seeds of *Kalmiopsis* are available from horticultural sources. Wiley (1968) includes *Kalmiopsis* in his somewhat eccentric self-published book, and recommends sowing seeds on the soil surface with a covering of very fine coal dust or granite to reduce moss growth. Wiley cautions that *Kalmiopsis* is very difficult to propagate from seed. However, Kruckeberg (1996) states that germinating seeds of this species is easy, and suggests treating them “as if they were dwarf Lapponicum rhododendrons,” but does not give specific germination instructions.

Fortunately, germination tests of *Kalmiopsis* seeds constituted a portion of a study evaluating edaphic preferences of this genus (Marquis 1977). In this study, addition of organic material from an Umpqua River *K. fragrans* site to the growth medium increased germination, and seeds heated prior to germination fared poorly. This research provided the basis for the selection of treatments, and for the expected germination timing and rates used in the germination and cultivation portion of our study.

Objectives

The main objective of this study is to determine the long-term viability of *Kalmiopsis fragrans* populations damaged during fires in 1996 and 2002. The goals for the third year of the study are to:

1. *Collect third year data at all three study sites*. Photograph plots established in 2004, and collect data similar to previous years' on selected reproductive parameters.

2. *Compare field data collected from 2004, 2005 and 2007.* Evaluate growth and reproduction by comparing data from 2007 with previously collected data.

3. *Develop a seed germination protocol.* Assess the effect of three planting substrates and two temperature regimes on the germination of *K. fragrans* seeds.

Methods

Monitoring site selection

Three sites, each with 10 randomly selected plots, were selected in 2004. Site selection was based on the following criteria: site accessibility, accessibility of plants within sites, population size (with preference for larger populations), and (for the treated sites) the presence of burned plants. An unburned forested site (526), and two fairly open burned sites (Ash Creek – burned in 2002, and Dry Creek – burned in 1996) were selected for inclusion in this study (Figure 2). Detailed maps and directions to all sites are provided in the attached appendix.

Plot selection

Within each site, plots were randomly selected from a pool of potential plot locations. (For details on the plot selection process, see Mitchell and Meinke 2004.) After selection was completed, the precise location of each plot center was marked with a numbered tag attached to a nail or heavy wire.

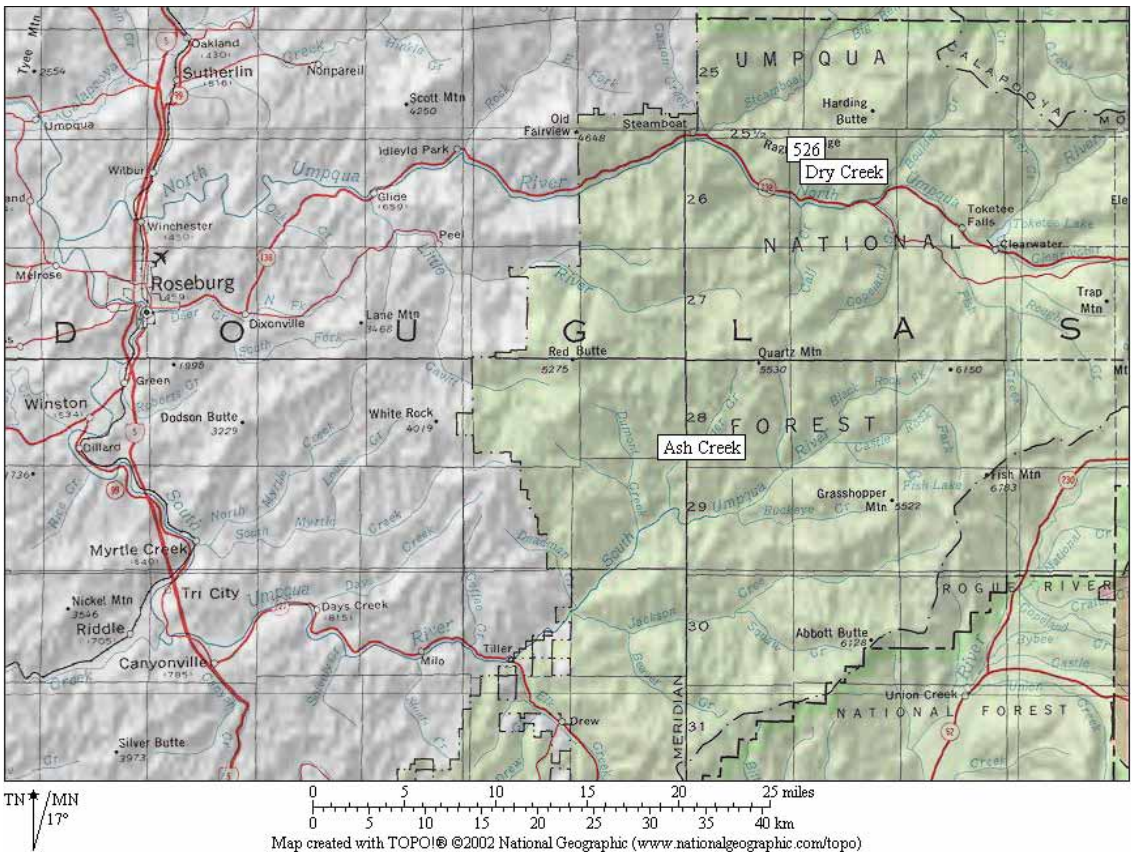

Figure 2. Locations of *Kalmiopsis fragrans* study sites in the Umpqua National Forest. Dry Creek and 526 sites are located in the watershed of the North Umpqua River, and the Ash Creek site is located in the South Umpqua River watershed.

Plot size and shape

Due to the difficulty in marking plots in the rocky soils, a circular plot shape was used; circular plots need only one central plot marker, whereas any other shape requires at least two. A plot frame, constructed from a plastic hoop, cut into 4 sections for transportability and fitted with dowels for reattaching, was used to delineate each plot's boundary. The inner diameter of the frame was 84 cm, making the plot area 0.5542 m^2. In 2005, the plot frame was improved by the addition of two elasticized strings on selected radii to facilitate centering the frame over the plot center.

Plot maintenance

Plot center markers were largely intact at our 2007 visit, although one plot marker at the Dry Creek site required replacement using location information from a photo from the previous year. It was also necessary to move fallen bark and a live tree to photograph two plots at this site. As snags continue to fall in the two burned sites, removing fallen trees and debris from plots will continue to be necessary in future years. As in 2005, some of the plot centers at the 526 site needed to be relocated using distance and azimuth from landmarks because vegetation had covered the tags.

Data collection

Many studies use biomass as a measure of growth (Stark and Steele 1977, Keeley and Keeley 1984, Hobbs and Mooney 1985, Vila and Terradas 1995). However, destructive measures are not appropriate when studying a rare plant. Other studies (Hobbs & Mooney 1985, Mills 1986, Matlock et al. 1993, Vlok & Yeaton 2000) use stem number or plant density as a measure of growth, but this does not work well for a mat-forming, clonal shrub like *K. fragrans*. Due to these limitations, the percent of the plot covered by *K. fragrans* and the number of inflorescences present within each plot were measured to evaluate plant growth in this study (Figure 3). Similar measures have been used successfully to evaluate the post-fire growth of chaparral shrubs in California (Stark and Steele 1977, Keeley and Zedler 1978).

Figure 3. Katie Mitchell carefully studies a plot at the Ash Creek burn site. Photo by I. Silvernail.

To generate the percent cover measurement, a photo was taken of each plot in the spring of 2004, 2005 and 2007 (see "Photography" section below for specifics) and the percent of that plot covered with *K. fragrans* was calculated using SigmaScan® software (Systat 2005). To improve reproducibility when calculating cover, only the percent of *K. fragrans* that was visible in the photograph was used in our calculations. This method resulted in a possible underestimation of cover for plots in which the vegetation of the target species is covered by other plants, but eliminated observer subjectivity when analyzing the photos.

When counting inflorescences, an inflorescence was defined as the part of a stem with flowers or fruits. When branching occurred along a stem, inflorescences were counted separately when vegetative leaves (with no reproductive parts in the axils) occurred between the inflorescences. An inflorescence was counted only if one or more of the flowers or fruits fell within the plot. The total number of inflorescences per plot was counted and this number was adjusted to account for the differences in percent cover among plots. The number of inflorescences per plot was converted to the number of inflorescences per square meter of *K. fragrans* cover by dividing the number of inflorescences by the area of the plot covered by *K. fragrans* [#infl/m^2 = (# infl/plot) / (% cover * 0.5542 m^2)].

During the course of collecting data in 2005, we observed that the number of flowers per inflorescence varied among sites. Subsequently, 10 inflorescences in each of three plots were selected at each site, and the number of flowers per inflorescence was counted. In order to minimize bias with regard to inflorescence size or number of flowers when selecting the 10 inflorescences to be counted, inflorescences closest to the researcher were selected. These data were also collected in 2007.

Photographic methods

Photographs were taken with a Nikon® CoolPix 995 digital camera, using the normal resolution setting. The camera was positioned perpendicular to the slope of the ground at the plot center, and set high enough to include the whole plot frame, without encompassing excess out-of-plot area. The height above ground varied from 137 to 167 cm, depending on the height of the vegetation. The nail head, or the center of the bend in the wire, defined the plot center.

Seed collection

Seed is routinely produced by this species and can be readily collected (Marquis 1977, Meinke and Kaye 1994). Mature fruits, immature fruits, and empty capsules from the previous year are often all present on plants within the same population (Figure 4). In July 2005, 20 mature fruits containing ripe seeds were collected from each of 20 plants at two sites: our 526 control site, and Limpy Rock (a well known location for *K. fragrans* that was not used for the monitoring portion of our study).

Figure 4. *Kalmiopsis fragrans* fruit phenology on July 28, 2005. Shoot A has old fruits from a previous year, shoot B has immature fruits, and shoot C has mature fruits. Photo by K. Amsberry.

Seed germination

In November 2005, *K. fragrans* seeds were planted in pots filled with one of three substrates: standard potting mix (Professional Grower's® SB40), standard potting mix with a layer of ground charcoal (from burned logs) on top, or a mix of native soil (collected from the 526 site) and standard potting mix in the top half of the pot (and straight potting soil in the bottom half). The very small size of seeds of this species made counting individual seeds very difficult, so 40 pots of each substrate were planted with a sprinkling of seed collected at the Limpy Rock and 526 sites (see above). Sixty pots (20 from each treatment) were then placed outside in the greenhouse yard and the other 60 pots were placed in the greenhouse. Bark was packed around pots in the greenhouse yard to protect them from freezing during the winter. In February 2006, pots were checked to assess establishment of *K. fragrans* seedling. Each pot was recorded as having either many (more than 10), a few (less than 10), or no *K. fragrans* seedlings present.

Results

Percent cover

Percent cover of *K. fragrans* was greater at the unburned site (526) than at either of the burned sites at the beginning of our study, and remained higher throughout the study period (Figure 5). Plots at the Dry Creek site (burned in 1996) initially had higher cover values than those at Ash Creek (burned in 2002), but by 2007 the percent cover value for both of these sites was the same (14.5%).

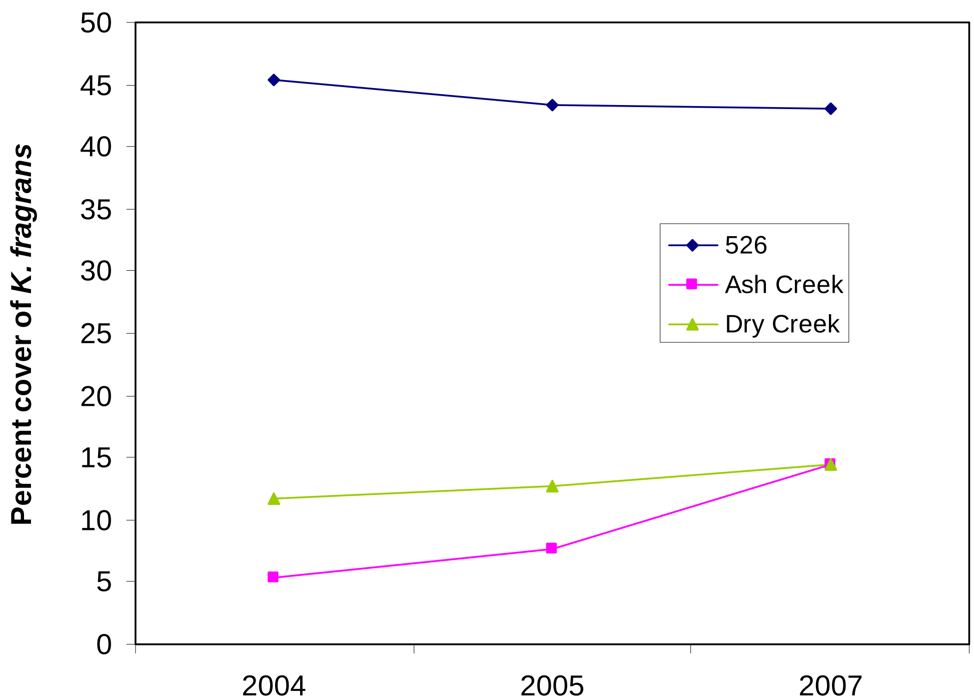

Figure 5. Mean percent cover of *Kalmiopsis fragrans* at three sites in 2004, 2005, and 2007. (n=10 plots/site/year)

Change in percent cover from 2004 to 2007

Percent cover at the 526 site decreased slightly between 2004 and 2007 (although this decrease was not significant; paired t-test, two sided p-value=0.57, 95% confidence interval from -9.6% to 5.1%) and increased at both the Ash Creek and Dry Creek sites (Table 1; Figure 5). This increase in percent cover at both burned sites was signficant over the three year study period. Cover at Ash Creek increased a total of 9.1% over the course of the study (paired t-test, two sided p=0.017, 95% confidence interval from 3.0% to 15.2%), and increased a total of 2.8% at Dry Creek (paired t-test, two sided p=0.018, 95% confidence interval from 0.9% to 4.7%).

Table 1. Change in percent cover of *Kalmiopsis fragrans* at the three study sites from 2004 to 2007.

	526	**Ash Creek**	**Dry Creek**
Mean change	-2.2% ± 3.8%	9.1% ± 3.1%	2.8% ± 1.0%
Range of values	-32.0% to 8.1%	-5.4% to 28.4%	-3.7% to 7.9%

(n = 10 plots/site, displayed errors were calculated as standard errors of the mean.)

Number of inflorescences per m²

The number of inflorescences per plot was adjusted to account for differences in *K. fragrans* cover in each plot. The number of inflorescences per m^2 of *K. fragrans* cover at the unburned control site remained significantly lower (and fairly stable) than the number at the burned sites throughout the study period (Figure 6; Table 2). Plants in the Ash Creek site exhibited a large increase in the number of inflorescences produced between 2004 and 2005, with another small (non-significant) increase between 2005 and 2007. Plants at Dry Creek produced more inflorescences per m^2 in 2005 than they had in 2004, and then exhibited a drop in inflorescence production in 2007.

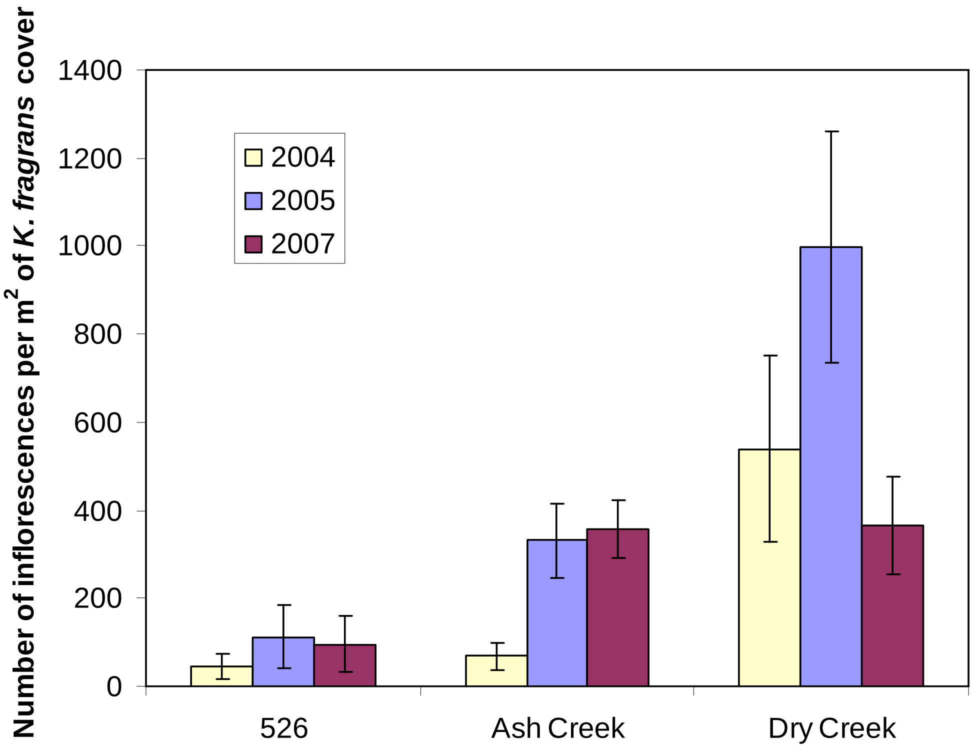

Figure 6. Mean number of inflorescences per m^2 of *Kalmiopsis fragrans* cover at three sites on three sample dates. (n = 10 for each site). Error bars represent one standard error above and below the

Table 2. Mean number of inflorescences per m^2 of *Kalmiopsis fragrans* cover at the three study sites in each monitoring year.

	2004		**2005**		**2007**	
Site	**Mean ± SE**	**Range**	**Mean ± SE**	**Range**	**Mean ± SE**	**Range**
526	45.8 ± 28.2	0-291	112.1 ± 70.6	0-700	95.0 ± 64.2	0-647
Ash Creek	68.0 ± 30.5	0-844	330.8 ± 84.0	0-260	357.6 ± 64.4	0-565
Dry Creek	538.0 ± 211.5	0-2076	997.3 ± 261.8	130-2551	365.0 ± 112.0	0-1193

Number of flowers per inflorescence

Both site and year had a significant effect on the average number of flowers produced per inflorescence (p<0.001 for site, year, and the interaction of site and year from a two-way ANOVA). Plants in the Ash Creek site produced a higher average number of flowers per inflorescence than those in the other sites in both years in which this variable was measured (p<0.001 from one-way ANOVA; Figure 7). Plants in all three sites produced a lower average number of flowers in 2007 when compared to 2005, with the greatest difference between years evident at Ash Creek.

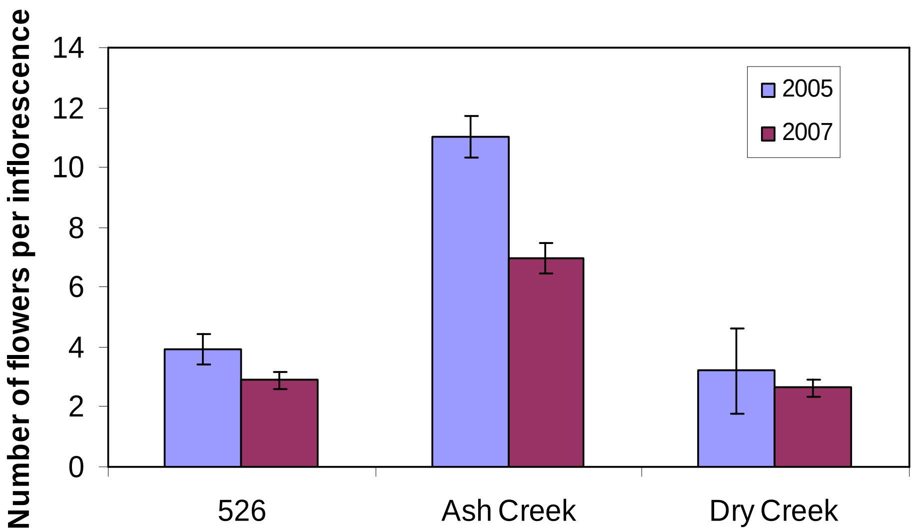

Figure 7. Number of *Kalmiopsis fragrans* flowers per inflorescence at three sites in 2005 and 2007. This variable was not measured in 2004. (n = 30 for each site; error bars represent one standard error above and below the mean.)

Estimated number of flowers per m^2 of **K. fragrans** *cover*

Because the number of flowers produced by an inflorescence differed among sites and among years in our study (Figure 7), the number of flowers per square meter of *K. fragrans* cover provides a more accurate assessment of reproductive output than number of inflorescences per meter. This value was calculated by multiplying the average number of flowers per inflorescence in the target site and year by the number of inflorescences per square meter of *K. fragrans* cover in the corresponding site and year. In 2005, plants in the Ash Creek and Dry Creek sites produced significantly more flowers per unit area of *K. fragrans* cover than those in the 526 site (p<0.001; Figure 8, Table 3). In 2007, both burned sites again produced more flowers per unit area than the unburned control, but the difference between values for the control and Dry Creek sites was no longer significant (Fisher's LSD).

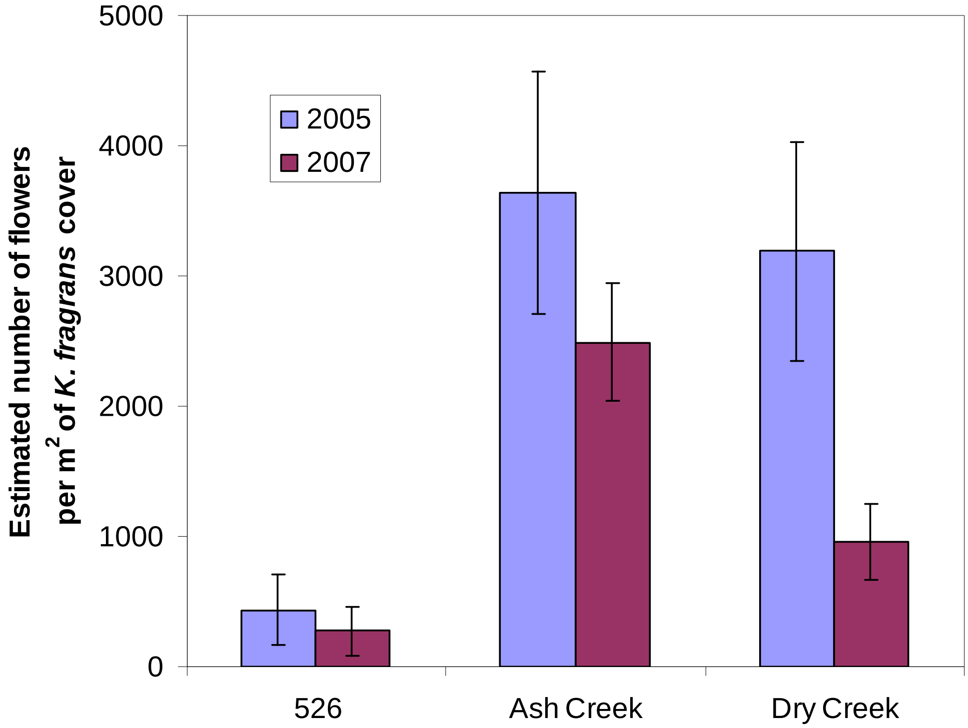

Figure 8. Estimated number of *K. fragrans* flowers per square meter of *Kalmiopsis fragrans* cover at three sites during 2005 and 2007. Estimates were computed by multiplying the average number of flowers per inflorescence by the number of inflorescences per square meter of *K. fragrans* cover. Error bars represent one standard error above and below the mean.

Table 3. Mean number of flowers per m^2 at the three study sites in each monitoring year.

	2005		**2007**	
site	**Mean ± SE**	**Range**	**Mean ± SE**	**Range**
526	437.1 ± 275.2	0-2732	275.4 ± 186.2	0-1877
Ash Creek	3636 ± 924.3	0-9295	2492.5 ± 449.2	0-3941
Dry Creek	3191.4 ± 837.6	416-7748	962.2 ± 294.5	0-3139

Herbivory

In 2005, all of the plots at the Dry Creek site showed evidence of herbivory, with many of the plant stems nipped off at the ends, probably by deer (Figure 9; Mitchell and Meinke 2005). In 2007, there were again signs of herbivory at this site. While herbivory was not the focus of the current study, quantifying the extent and effect of herbivory may be critical to understanding the population dynamics of *K. fragrans*, especially in some sites. Herbivores can play an important role in the composition of plant communities, and can alter the competitive balance between shrubs regenerating after fire (Mills 1986). Signs of herbivory were not clearly evident at Ash Creek or 526 in either year.

Figure 9. Close-up of *Kalmiopsis fragrans* at the Dry Creek site. Note the blunt ends of the stems. Photo by M. Carr.

Seed germination and seedling cultivation

Seedlings emerged in 88% of the 60 pots cultivated in the greenhouse (Figure 10). Substrate significantly affected seedling establishment (χ^2=12.5, $\chi^2_{critical}$=9.5 at α=0.05), with native soil showing the most success in promoting seed germination and plant growth (Table 4). Interestingly, pots with the native soil amendment also developed a greater cover of moss than those with the two other soil mixes. Seedlings of *K. fragrans* did not establish in the 60 pots cultivated in the greenhouse yard.

Figure 10. Many tiny seedlings of *Kalmiopsis fragrans* began to emerge three weeks after planting. Photo by T. Maddux.

Table 4. Number of pots in which establishment of seedlings occurred under greenhouse conditions (none = 0 plants established; few = 1-10 plants established, and many = more than 10 established).

Soil type	**Number of plant establishing**		
	none	few	many
charcoal amended potting mix	4	9	7
native soil amended potting mix	0	5	15
unammended potting mix	3	12	5

After germination, seedlings continued to grow, eventually maturing and flowering (Figure 11). Cultivation in the greenhouse was continued, with plants watered as the soil dried, and fertilized weekly with Dyna-Gro® at the manufacturer's recommended rate. Despite the growth of a dense carpet of moss on the soil surface, plants are currently thriving, with 51 pots each containing multiple healthy plants.

Figure 11. Plants continue to thrive in the greenhouse environment. Inset shows a plant in flower. Photos by M. Carr.

Discussion

Keeley (1987) identifies three strategies for re-establishment after fire by shrubs in California chaparral ecosystems. In this study, one set of shrubs re-sprouted from fire-resistant propagules (lignotubers), as well as emerging from a seed bank. The second group did not vegetatively regenerate after fire, but instead produced copious seed. The third group seldom produced seedlings after fire, and depended primarily on vegetative re-sprouting to re-colonize burned habitats. Initial observations indicate that *Kalmiopsis fragrans* falls into this last group, with plants resprouting from the crown after emergent foliage and branches are damaged by fire.

Plant growth

Following the pattern observed in the first two years of monitoring, the percent cover of *K. fragrans* at the 526 site in 2007 was much higher than at either of the two burned sites. This difference is probably due to the fire history of the three sites. The 526 site has not burned in the recent past, whereas the Dry Creek site burned in 1996 and the Ash Creek site in 2002. Although data quantifying the extent of the area inhabited by *K. fragrans* at these two sites prior to the fires are not available, post-fire observations of charred stumps and evidence of crown damage indicate that plants of *K. fragrans* suffered a reduction in biomass due to fire (Mitchell and Meinke 2004).

Marquis' (1977) dendrochronological evaluation of *Kalmiopsis* plants demonstrated that some individuals in his study sites were much older than the dates of known fires, indicating that at least a portion of the plants within a population were able to survive burning and re-sprout. In 2004, plants in our study sites that survived the fires but experienced crown damage produced new stems 5-15 cm in length (Mitchell and Meinke 2004). Additionally, no seedlings were observed at these sites during the course of this study (and only one seedling has ever been observed in any *Kalmiopsis* population), indicating that the increase in cover from 2004 - 2007 represents vegetative growth of individuals that survived the fire.

Not only did plants resprout after exposure to fire, they also grew at a greater rate than those in the unburned control site. The size of the population of *K. fragrans* at the 526 site (as measured by the average percent cover of our plots) was stable throughout the course of our study, with only slight annual variation, while populations in both the Dry Creek and Ash Creek sites experienced an increase in biomass. The unchanged percent cover at the unburned site, in combination with the slight increases in both years at the burned sites, suggests that *K. fragrans* is utilizing a "resprouting strategy" in order to recapture available habitat and recover from the damaging effects of fire. Post-fire resprouting has been observed in other ericaceous shrubs and provides a mechanism for plants to quickly colonize areas after fires (Verdaguer and Ojeda 2002).

However, post-fire regrowth is not always rapid, and low cover in the first years after fire has been observed for re-sprouting ericaceous shrubs in California chaparral (Keely and Zedler 1978). The low post-fire percent cover and slow regrowth of *K. fragrans* in our study sites may not be cause for concern, as this scenario may represent a common situation for this species. Interestingly, the age of shrubs can also influence their ability to regrow after fire, with regrowth rates declining with stand age (Hobbs and Gimingham 1984). Although one plant of *K. fragrans* at Limpy Rock was determined to be at least 60 years old (Marquis 1977), the age of the plants in our study sites is not known, making assessment of the importance of this variable on regrowth impossible to evaluate.

Although determining the mechanism that promotes increased growth associated with fire was not a component of the current study, previous research documents a variety of growth-inducing effects. Fire increases nutrient levels, heats the soil surface, and contributes to higher photosynthetic rates due to greater solar exposure (Hurlbert 1988). Nutrient levels of the soils in forested ecosystems are generally increased after fire, with higher levels of nitrates, exchangeable $NH_{4,}$ phosphorous, potassium and calcium reported in recently burned soils (Hernandez et al. 1997, Thorpe and Timmer 2005). In our study, plants in the more recently burned site (Dry Creek, burned in 2002) produced new growth at a greater rate than those exposed to fire in 1996. The burst of nutrients observed in soils after a fire is short-lived, allowing plants to prosper for a period of time, with a leveling off of this effect within a few years (DeLuca and Zouhar 2000). Nutrients levels of soils at the Ash Creek site have probably already declined, returning *K. fragrans* plants in this site to a slower growth rate.

As well as increasing soil nutrients, fire also promotes growth of some species by removing canopy cover and allowing more sunlight to reach the forest floor. In a recent study, an herb found in old-growth forests of the northwest (*Cimicifuga elata*) responded positively to increased solar exposure, producing more growth and exhibiting higher reproductive rates in sites in which canopy cover was reduced by clear-cutting (Kaye and Kirkland 1999). Because increased plant growth after fire is a response to one or more of the many environmental changes in habitat brought about by burning, observed increases are variable, and difficult to attribute to any one factor. The initial variation in growth rates between our two burned study sites (and the growth rate congruence observed this year) is probably due to various combinations of light, soil nutrients, herbivory, plant age, and other unknown factors.

Reproduction

Although data on the number of inflorescences were collected in all three monitoring years, the variation among sites in the number of flowers produced per inflorescence made comparison of this variable problematic. Inflorescences were smaller (but more numerous) at the Dry Creek site, probably due to the high levels of herbivory occurring here. Although herbivory of *K. fragrans* has not been previously reported, and was notably absent in most sites during Marquis' 1977 study, the removal of flowering and vegetative shoot tips (presumably by mammals) was common at the Dry Creek site in 2005 and 2007. A well-documented physiological response to removal of shoot tips is subsequent auxiliary branching (Hopkins 1995), and this type of branching apparently occurred on inflorescences in the Dry Creek site following herbivory. An herbivore exclusion study at these three sites would provide valuable data as to the extent and effects of herbivory on *K. fragrans*.

Reproductive output, as measured by the number of flowers per occupied m^2, differed among sites, with plants in both burned sites flowering more prolifically than those in the control site. The intact canopy cover at the 526 site probably contributes to the low flower production in this site, as *Kalmiopsis* appears to be shade intolerant, with plants becoming etiolated and producing few or no flowers in sites with substantial canopy development (Marquis 1977, Carlson and Meinke 1998). Plants of *K. fragrans* in the burned sites, once they recovered from the fire itself, are probably responding to increased sunlight by blooming more profusely. Lack of canopy closure has been associated with increased reproduction of other species in northwest forests (Kaye 1993, Kaye and Kirkland 1999), as well as in other conifer dominated systems (Norden and Kirkman 2004). The sporadic creation of canopy openings by fire (or other disturbance) is presumed to be critical to the persistence of these species.

Decreases in associated aboveground vegetation, reduction in biomass, and increases in nutrient levels also enhanced flowering and fruiting of plants in non-forested fire-prone ecosystems; the interactions among these casual factors were also complex (Hurlbert 1988, Ellsworth 2007). Additionally, herbivory by ungulates confounded evaluation of the recovery of shrubs after fire in an Arizona pine forest (Huffman and Moore 2004). In the Arizona study, the increased growth and reproduction of *Ceonothus fendler*i resulting from burning were also associated with a decrease in plant size and flowering due to increased ungulate herbivory. More data from future years of monitoring will help to quantify trends among populations of *K. fragrans*, and elucidate the causes for the variation in growth and reproductive output observed thus far.

Seed germination

In our study, seeds exhibited no physiological dormancy and germinated easily under standard greenhouse conditions. Germination rates, and the time period that was required for germination to begin after sowing, were similar to those reported in previous literature (Marquis 1997). The ready germination of these seeds in a greenhouse environment indicates that the low seedling recruitment observed in all *K. fragrans* sites is not due to inherent genetically- or environmentally-based inviability of available seed. Instead, the lack of seedling recruitment observed in the field may be due to poor environmental conditions for germination (and/or seedling emergence) in all sites currently occupied by *K. fragrans*. Harsh conditions in the rocky, thin soils where this species occurs may cause high pre-germination mortality, or the thin coats of the seeds may be easily damaged by fungal colonization.

Alternatively, seed may germinate readily in the field, followed by high seedling mortality and low establishment. Once seedlings emerge they may die of desiccation or freezing, may be selectively eaten by herbivores, or may succumb to disease. Additionally, the diminutive stature and slow growth of emergent seedlings may allow them to be easily out-competed by associates (such as *Arctostaphylos*) with faster germination and larger seedlings (Marquis 1977). (However, in our study, lack of competition alone did not promote seedling emergence, as seed sown in pots in the OSU nursery yard did not germinate under ambient outdoor conditions, despite the lack of competing vegetation.) Because the locations of most populations are difficult to access for much of the winter and early spring, the observed lack of seedlings may be due to lack of observation during the short time that seedlings are visible before dying, rather than lack of seedlings emerging. It is also possible that both germination and establishment may occur occasionally when conditions are appropriate - again, because most sites are not visited frequently, these sporadic establishment events may occur unobserved.

Seeds germinated at a higher rate, and seedlings grew more quickly, in native soil than in potting mix in our study, as well as in previous studies (Marquis 1977). This increased growth and germination may be due to the ability of native soils to promote the creation of ericoid mycorrhizae by providing access to the appropriate ascomycete fungus. The seeds of many ericads, including *Kalmia*, require the development of a mycorrhizal association in order to germinate and grow (Flemer 1949, Cripps and Eddington 2005), and such an association may be required by *K. fragrans*. The distribution of mycorrhizal fungus can influence the distribution of rare obligately mycorrhizal plant species (Gisler and Meinke 2001), with plants unable to persist in sites lacking the proper associate. The lack of seedlings observed in the field may be due to the inability of the seed to come into contact with the appropriate fungal species. Some sites (especially after burns) may not support the appropriate fungal species, preventing the development of this critical interaction.

Our germination and cultivation work demonstrates that plants of *K. fragrans* can readily be grown from seed under standard greenhouse conditions. Although designating site selection criteria and developing a protocol for outplanting transplants remain daunting tasks, our ability to produce cultivated stock available for outplanting is the first step in the process of creating new populations of this rare species. The ability to cultivate "populations" of this species in the greenhouse also provides the opportunity to initiate research projects under controlled conditions. Additional studies on the ecology and breeding system of *K. fragrans*, with the goal of providing information useful for the conservation of this unique taxon, are scheduled for the near future.

The development of a protocol for growing plants from seed also reduces the need for collection of plants from naturally occurring sites for commercial, as well as research purposes. Although the popularity of *Kalmiopsis* as a garden ornamental seems to have waned currently, both species in this genus have been at risk from collection in the past (Meinke and Kaye 2007). The ability to propagate plants from seed allows for adequate stock to be produced for horticultural uses without affecting native populations.

Summary

- Plots established at three study sites in 2004, and monitored in 2005, were revisited for additional population monitoring in 2007. Data on percent cover, number of inflorescences per plot, and number of flowers per inflorescence were collected.

- Percent cover of *K. fragrans* has increased since 2004 at both Ash Creek and Dry Creek, and has remained stable at the unburned 526 site.

- The number of flowers per unit area covered by *K. fragrans* is generally higher at both the Dry Creek and Ash Creek sites when compared to the unburned 526 site.

- Plants at Ash Creek produced more flowers per inflorescence than those at the Dry Creek and the 526 sites. Shade (at the 526 site) and herbivory (at Dry Creek) contribute to this difference.

- No seedlings or juvenile plants were observed at any of the sites in 2004, 2005, or 2007.

- In the greenhouse, seed germinated and seedlings grew readily under standard cultivation conditions.

- Seed germination was higher on medium amended with native soil from a site occupied by *K. fragrans*.

- Plants matured and flowered in the greenhouse, providing opportunities for studies under controlled conditions.

Recommendations

- Continue monitoring permanent plots established at two recently burned sites (Ash Creek and Dry Creek) and one unburned site (526).

- Quantify differences among sites by evaluating soil characteristics (pH, nutrient levels, particle size), light levels and associated vegetation at the three sites.

- Revisit *K. fragrans* populations included in research completed prior to the current study (i.e. Marquis 1977 and Carlson and Meinke 1998) in order to evaluate changes in these sites based on previously reported data.

- Design and implement an herbivore exclusion experiment to determine to what extent herbivory affects the growth and reproduction of *Kalmiopsis fragrans* plants at the Dry Creek site.

- Continue germination research by using field trials to evaluate the ability of seeds to germinate under various outdoor conditions.

- Use cultivated plants to evaluate heterostyly, and complete additional pollination studies on *K.fragrans* and *K. leachiana*.

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Appendix

Site Locations

All latitude/longitude coordinates are taken from a Garmin GPS unit, in WGS 1983 coordinate datum. All cardinal directions are from magnetic North, not true North. Magnetic declination at these locations during the time of plot set-up was 16° 50’ E for the Dry Creek and 526 sites, and 16° 47’ E for the Ash Creek site.

1. **526 Site**

   Directions:

   Driving: Take the North Umpqua River Road (highway 138) East past Steamboat. Turn left on FS 4713. Set the trip odometer to zero. After 4.5 miles, take a right on road FS 100 where the sign reads, “Bradley Ridge Trail.” At mile 7.7 take a right at the junction (if you followed the road to the left, there would soon be pavement) onto an unnumbered road (FS 120 on the map). A little way down the unnumbered road on the right, there is an orange sign that reads, “Gate Ahead 0.2 Miles.” Go through the gate (7.9 miles). You will pass Limpy Rock on the right at mile 9.3. The pull-out for the 526 site is at mile 10.5 on the right, where there is a dirt pile under a tree and many small Douglas fir trees.

   Walking: From the pull-out, the site is just beyond the small trees on the road. You will see the sign post for the 526 tree, and not too far beyond is the 526 tree which is well-marked on the side facing the road. The plots are mostly between the 526 tree and the rock, a few on the rock, and one on the left (East) side of the rock.

   Landmarks:

	526 tree	N 43.32647°	W 122.62249°
65	boulder	unable to get satellites	

526 Site Landmark Photos:

526 tree

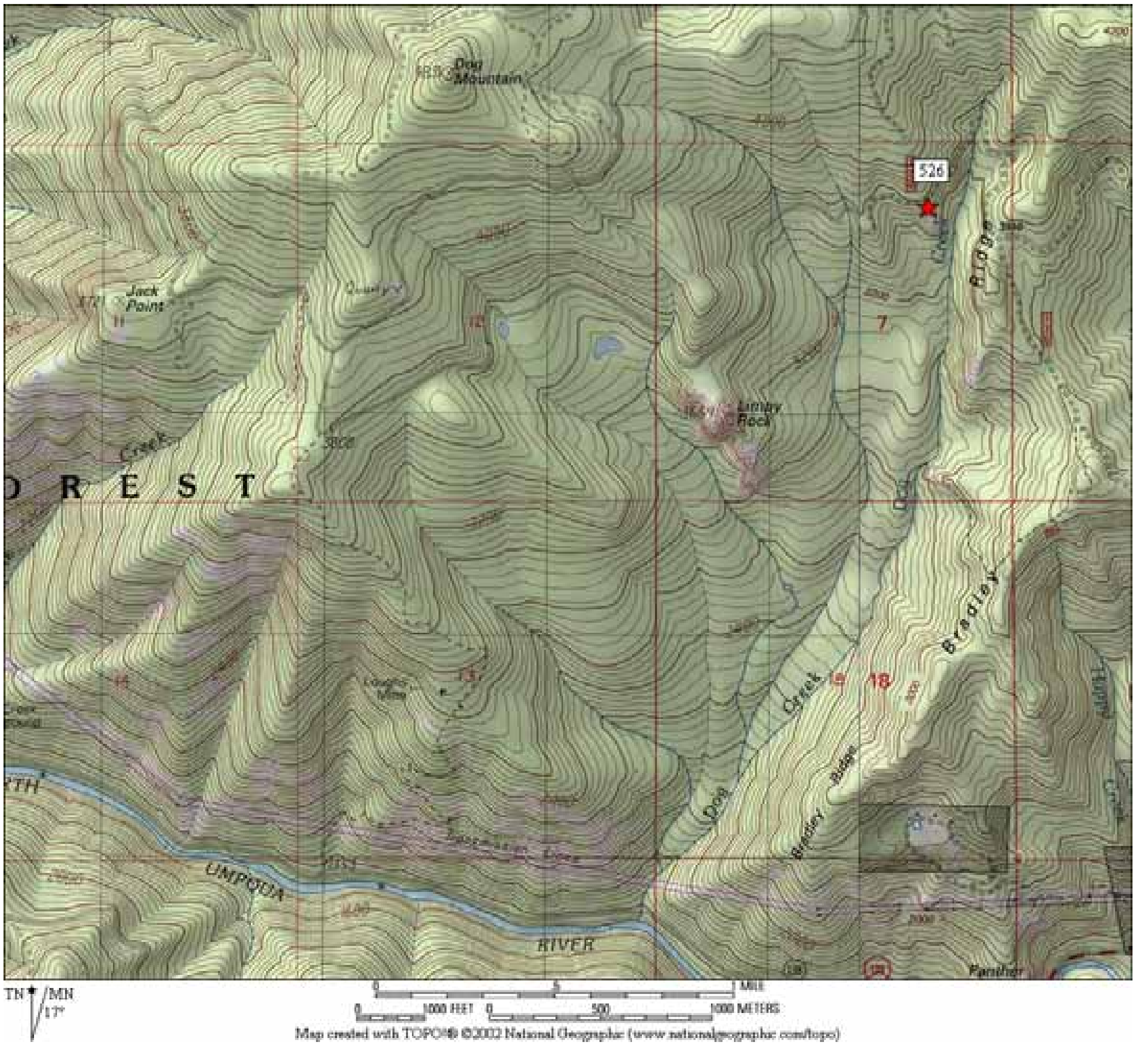
trap tree

boulder landmark #65 on the east side of the rock

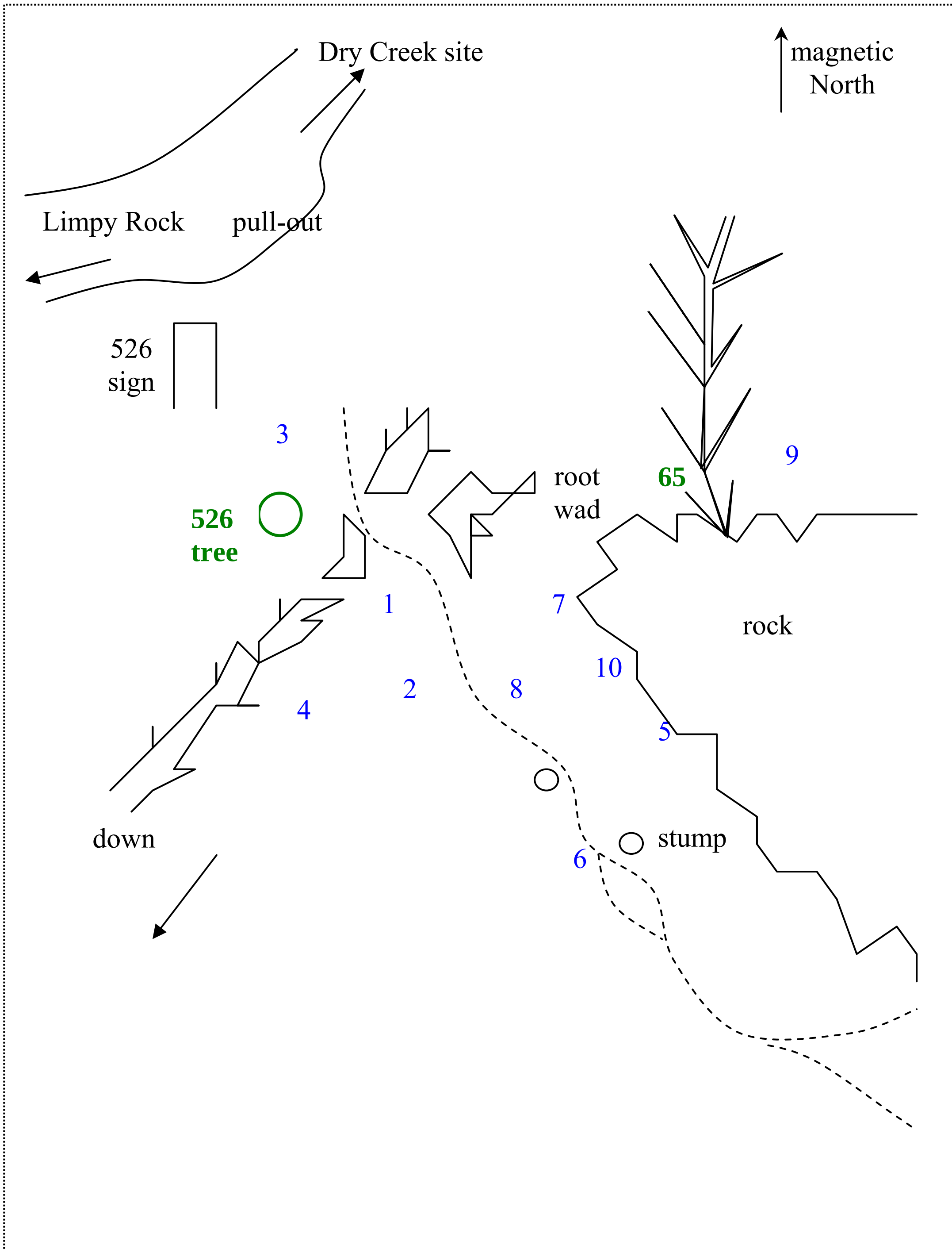
526 Site Plot Centers:

#	To:	Direction from plot center:		Distance (m):
1	526	63° E of S	SE	4.20
2	526	44° E of S	SE	8.48
3	526	13° W of N	N	3.65
4	526	10° E of S	S	8.02
5	526	58° E of S	SE	15.33
6	526	28° E of S	SE	14.67
7	526	75° E of S	E	12.02
8	526	56° E of S	SE	9.38
9	65	81° E of S	E	6.39
10	526	65° E of S	ESE	12.60

Map:


Dog Mountain
Jack Point
Limpy Rock
Creek
R E S T
526
Ridge
Bradley
Dog
Creek
Bradley
Ridge
UMPQUA
RIVER
Panther
TN
MN
17°
MILE
1000 FEET
1000 METERS
Map created with TOPO!® ©2002 National Geographic (www.nationalgeographic.com/topo)

526 Site Rough Sketch:



2. **Ash Creek Site**

Directions:

Driving: Take the South Umpqua Rd (FS 28) from Tiller. After milepost 17, turn left on Ash Creek Road (FS 2826). Set your trip odometer to zero at this junction. After 1.3 miles, you will reach the first cattle guard. The second cattle guard is at 3.05 miles. Continue on Ash Creek Road (do not turn off on any lesser roads). The trip odometer should read 5.75 at the parking spot for this site, however, there is a better place to turn around at 6.05. It is recommended to continue to the turn around, and then come back to park at the site. The parking spot is in a saddle.

Walking: From the parking spot, head to the hill to the SW (pictured in the first photo), follow the flagging (yellow with black stripes). The flagging will take you along the side of the ridge and then downhill along the ridge line. Be sure to stay on the top of the ridge so you will not be mislead by any side ridges. You will know when you are nearing the population when you have passed through the rhododendrons.

Landmarks:

	parking spot	N 43.09306°	W 122.72694°
63	boulder	N 43.09477°	W 122.73518°
64	boulder	N 43.09471°	W 122.73540°

Landmark Photos:

parking spot in the saddle, follow log on the left up the hill to the flagging

view down the ridge along the way to the site

view of saddle parking from the opposite side

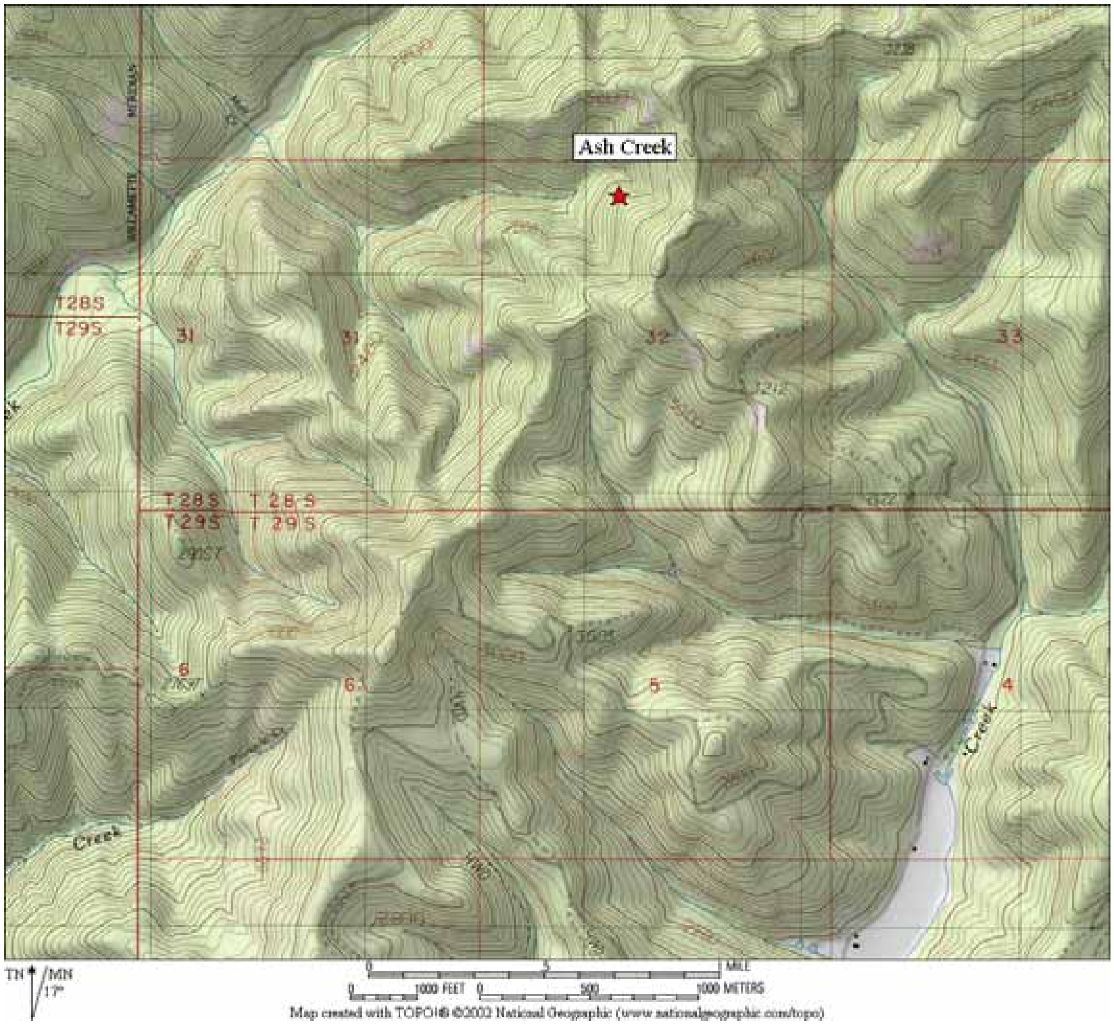
View downhill from #63 boulder

Ash Creek Plot Centers:

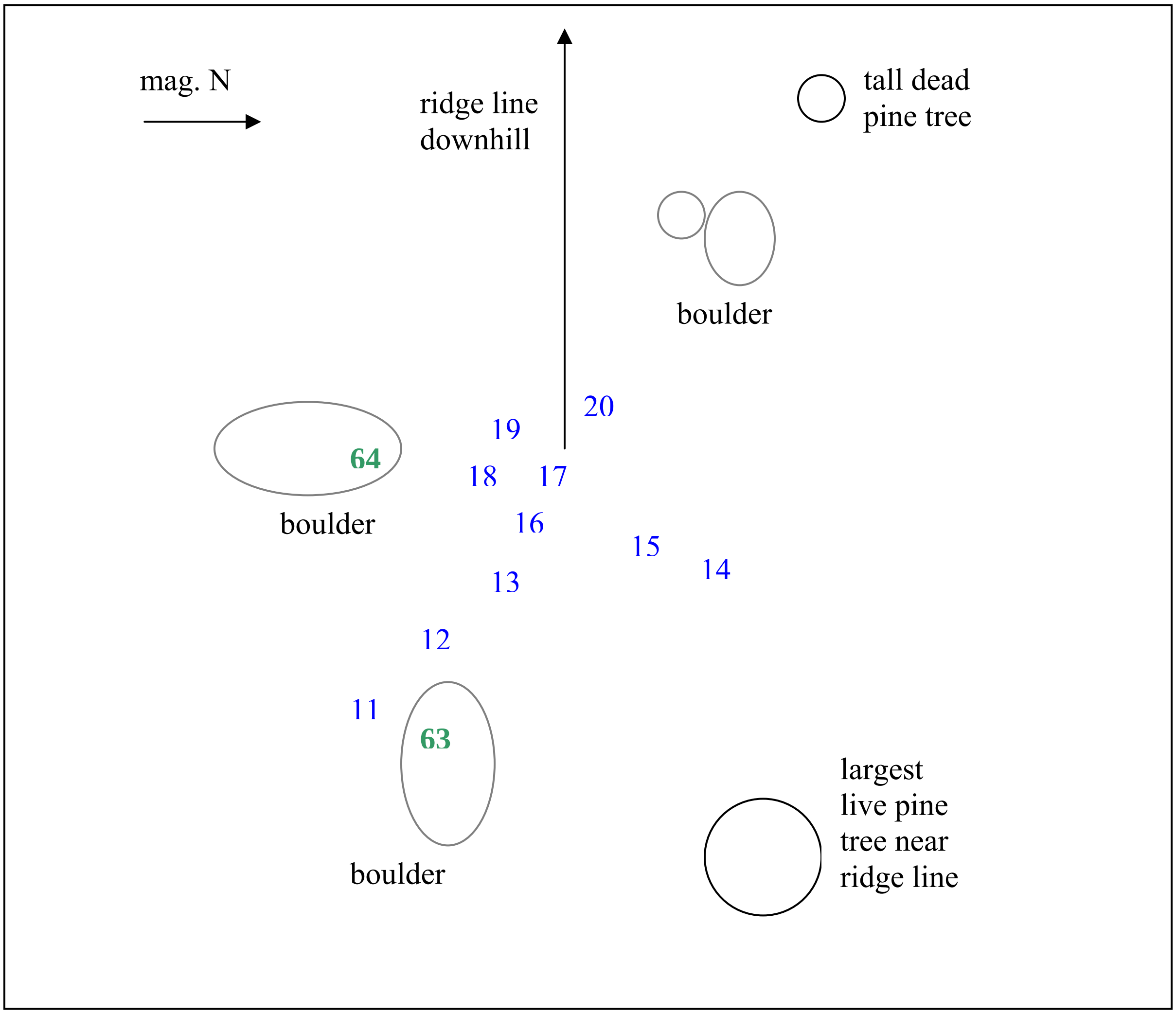
#	From:	Direction to plot center:		Distance (m):
11	63	19° W of S	S	1.92

12	63	69° W of S	WSW	3.50
13	63	74° W of S	WSW	7.88
14	63	66° W of N	WNW	7.34
15	63	76° W of N	WNW	7.75
16	64	44° E of N	NE	11.25
17	64	23° E of N	NE	8.71
18	64	31° E of N	NE	4.71
19	64	1° E of N	N	6.59
20	64	20° W of N	N	8.47

Map:


Ash Creek
T28S
T29S
31
32
33
T 28 S
T 29 S
6
5
4
Creek
Creek
TN
MN
17°
0
.5
1 MILE
0
1000 FEET
0
500
1000 METERS
Map created with TOPO!® ©2002 National Geographic (www.nationalgeographic.com/topo)

Ash Creek Rough Site Sketch:



3. Dry Creek Site

Directions:

Driving: Follow the directions to the 526 site, and continue along the road past it. Take a left at the junction (do not take road 130) 0.8 miles past the 526 site. Park at the end of the road (2 miles past the 526 site).

Walking: There is a closed road (shown on the map) to the right (SE) of the end of the road. Walk along this road to the end, where there is a path continuing along the ridge. The path is marked with flagging. Follow the ridge and the flagging until you reach a place where pink flagging is tied around three trees forming a triangle. At this point, head downhill following the flagging. Soon, you will reach an area where the forest canopy will have fallen to the ground due to fire. It is difficult to traverse all of the downed trees on the way to the rock outcrop on this side ridge, however, once through it you are at the site. Look for the metal pipe along the top of the ridge, and the boulder further down the ridge line as the landmarks (see the site sketch).

Landmarks:

	road end	N 43.32751°	W 122.60211°
61	boulder	N 43.32093°	W 122.59757°
62	metal pipe	N 43.32120°	W 122.59754°

Landmark Photos:

intertwined pines, looking down ridge

#62 pipe – behind the notebook, looking down ridge

#62 pipe

#61 boulder

looking towards the site, the light green knob in the middle, through downed and young trees on the way

Three trees in a triangle with pink flagging: turn downhill to go to the site

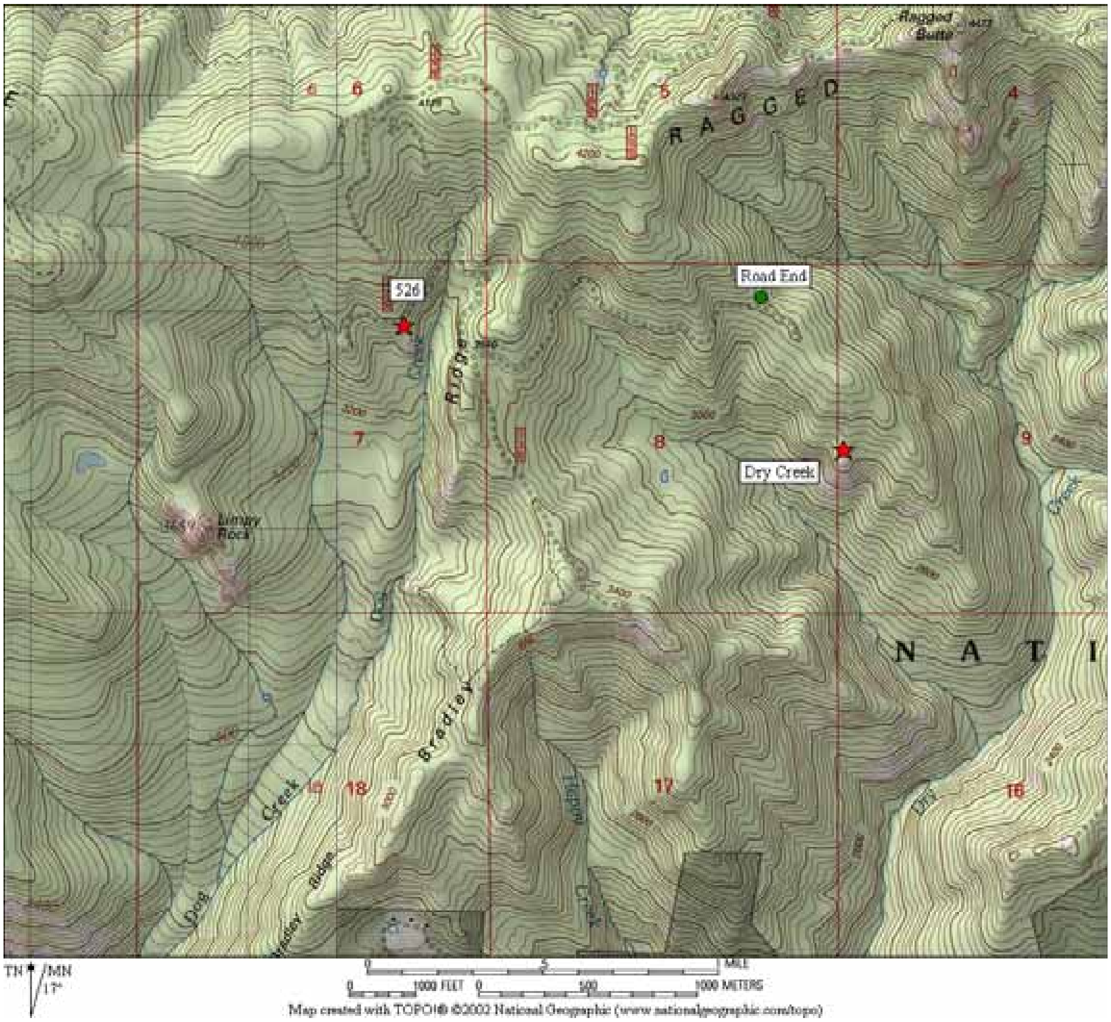
end of the closed road, path along ridge between the madrones on the left (photo

close-up between the madrones, showing flagging

Dry Creek Site Plot Centers:

#	From:	Direction to plot center:		Distance (m):
21	61	39° W of N	NW	11.49
22	61	4° W of N	N	9.13
23	61	6° E of N	N	13.58
24	61	10° W of N	N	15.42
25	61	10° W of N	N	16.64
26	62	30° W of S	SW	6.37
27	62	83° W of S	W	3.97
28	62	28° E of N	NE	10.09
29	62	59° E of N	NE	5.76
30	62	68° E of N	ENE	8.20

Dry Creek Site Map:



Dry Creek Site Rough Sketch: